Lessons for Climate Stabilizing Innovation from Experience with Cap-and-Trade Programs

Margaret Taylor

Goldman School of Public Policy
Univ. California Berkeley

October 19, 2009

Today's road map

1. Background
2. Findings
   - Lower-than-expected allowance prices
   - Regulated firms employ a portfolio of "abatement channels"
     - Not limited to technology adoption
   - Inventive activity declines across technologies after trading begins
3. Discussion

Background

Clean technology, innovation, and policy

- "Dirty" technologies are
  - Entrenched in key sectors of the economy
  - Favored by cost, performance, sunk costs, network externalities…
- Clean technology development
  - Requires uncertain R&D plus surmounting of other obstacles b/t birth & maturity of a technology
    - Invention, adoption, diffusion, learning-by-doing…
    - Private sector an important source of innovation (of U.S. R&D expenditures b/t 1953-2004, 57% by industry w/no federal support)
  - Incentives are negatively affected by market failures of pollution & innovation
- Policy affects the conditions of clean technology markets
  - Some policies separately target the pollution market failure or the innovation market failure
  - However, policies that target the pollution market failure have indirect effects on clean technology innovation

Some of the policies in play

- Pollution oriented:
  - Direct
    - Cap-and-trade programs (CTPs)
    - Emissions taxes
    - Standards
  - Indirect
    - Tax credits
- Innovation oriented:
  - Public RD&D funding
  - Intellectual property laws

About cap-and-trade programs (CTPs)

- The most dominant climate policy instrument today
- Policy-makers set a cap on emissions and then allocate emissions "allowances" to polluting sources that are equivalent, in sum, to the cap
  - If sources can reduce emissions relatively cheaply, they can then try to sell excess allowances at whatever price the market will bear
- CTPs perform well on dimensions of:
  - Political feasibility
  - Environmental performance
  - Compliance cost
- CTPs should incentivize polluting sources to adopt a range of "abatement channels"
  - These include new lower-emitting production and modification of existing production
- CTPs are distinguished by the variability of the price signal

What do we know about CTPs and innovation?

- Theoretical/modeling literature ranks policy instruments on incentives for "innovation" by polluting firms (dates back to Zerbe 1970)
- Emerging consensus that relaxing assumptions changes the ranking of instruments
  - E.g., Requate & Unold 2003; Fischer, Parry, Pizer 2003; Montero 2002; Malueg 1989; Bauman 2003; Keohane 1999; Parry 1998
- Not a large empirical/observational literature
  - Innovation is a second-order effect compared to cost, performance

This paper

- Synthesizes the empirical research and presents new data on innovation
- Focuses on successful CTPs that reduce emissions from fossil fuel combustion and have had long-enough operations
  - How was compliance achieved?
  - How did inventive activity play out?

The CTPs

	Scope	Pollutant
Title IV of 1990 Clean Air Act Amendments	National	Sulfur dioxide (SO_2)
OTC/NBP, the Ozone Transport Commission/ NO_x Budget Program	Regional, seasonal	Nitrogen oxide (NO_x)

Similarities

- Occur in the U.S.
- Caps phased in
- Operate on similar emissions sources (primarily coal-fired power plants)
- Akin to CTPs for GHGs: control combustion emissions

Differences

- Pollutants
- Governance levels
- Treatment of banking

The four technologies

	Post-Combustion	Pre-Combustion	Combustion Modification
Pollutant	SO_2	SO_2	NO_x
	NO_x		
Technology	Flue gas desulfurization (FGD)	Coal cleaning	Low-NO_x burners
	Selective catalytic reduction (SCR)		Overfire air
Effectiveness	+	-	-
Expense	+	-	-

The Findings

The cast of actors

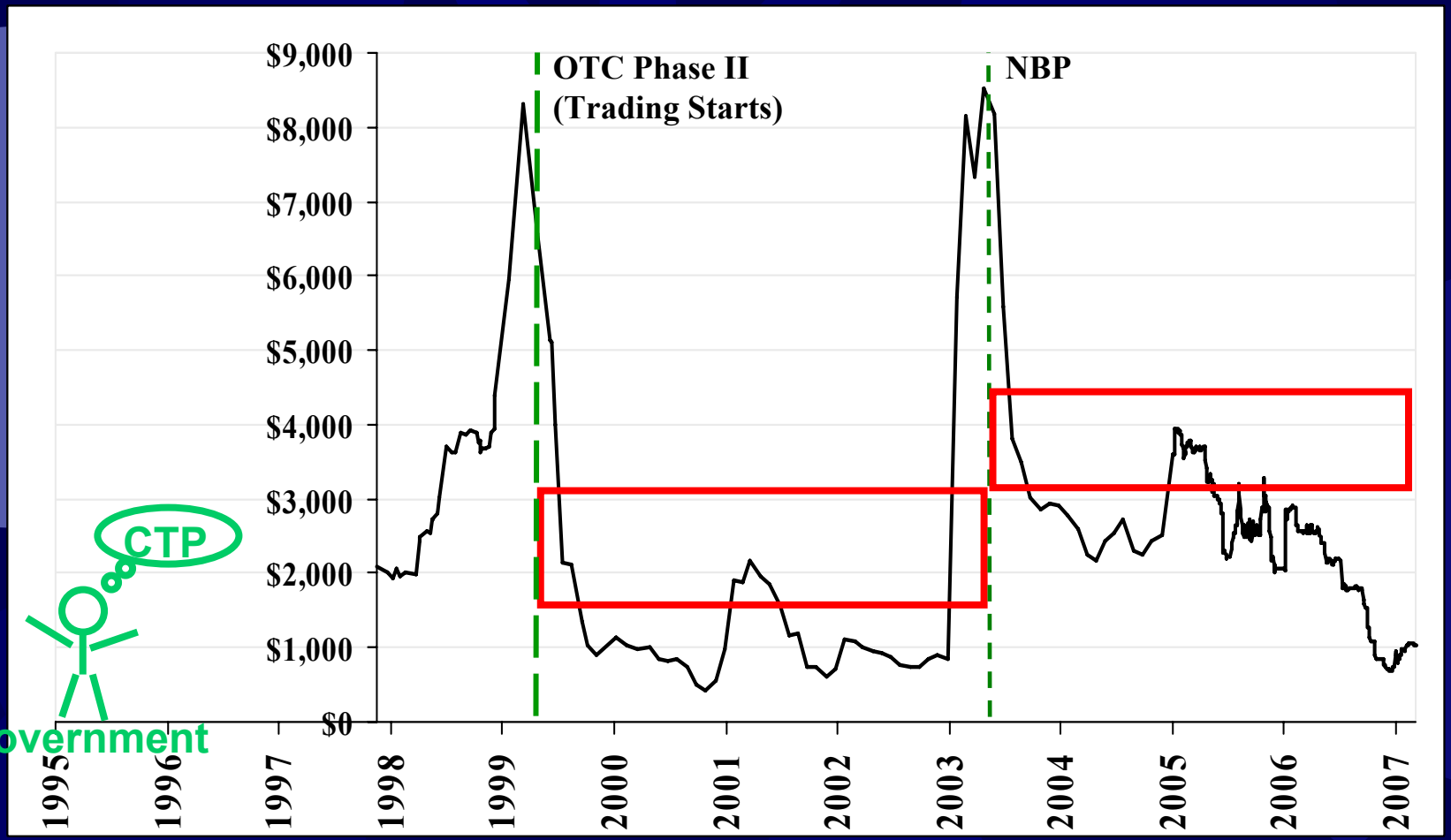
Polluters

Tech Suppliers

Government

Title IV Prices ($/Ton SO_2)

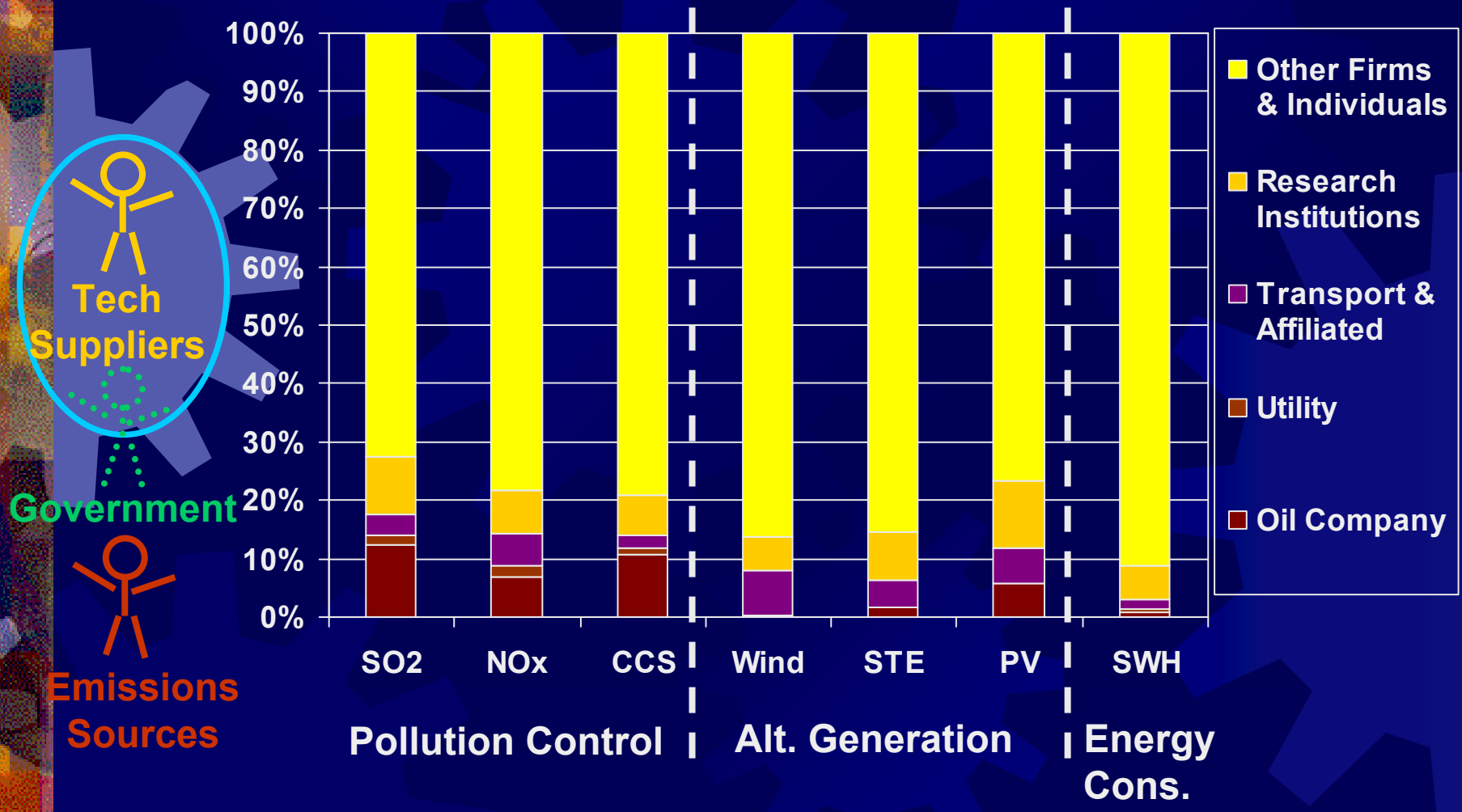
OTC-NBP Prices ($/Ton NO_X)



"Abatement Channels" used in compliance

- SO_2
  1. Switched to lower sulfur coals (1970s strategy)
  2. Balanced with post-combustion control
     - Either increased utilization of existing systems developed primarily over 20 years of TER & complementary policies, or
     - A smaller-than-expected number of new installations
       - Cancellations of in-progress installations ~19% of installed FGD capacity in Phase I (including one case in which $35 million had already been spent on FGD construction)
       - Keohane 2003 says less FGD than under counter-factual continuation of historic levels
- NO_x
  1. Utilized existing zero-emitting nuclear power plants and lower NO_x natural gas-fired power plants more extensively
  2. Purchased off-peak power from outside the region
  3. Benefited from better-than-expected performance from existing control technologies installed in response to TER phase of CTP & earlier TER & complementary policies

Intellectual property in clean tech



Patent breakdown in carbon relevant technologies by assignee type

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control

(b) Pre-combustion SO_2 control

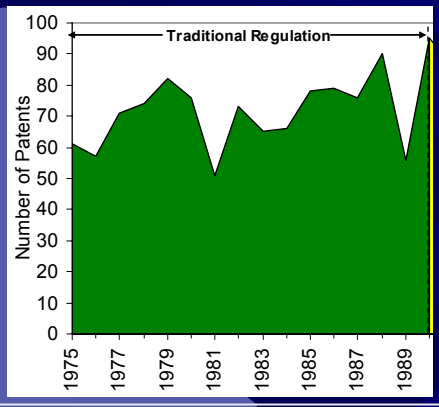
(c) Post-combustion NO_x control

(d) NO_x combustion modification

Traditional environmental regulation
Trading preparation (after passage, before actual prices)
Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

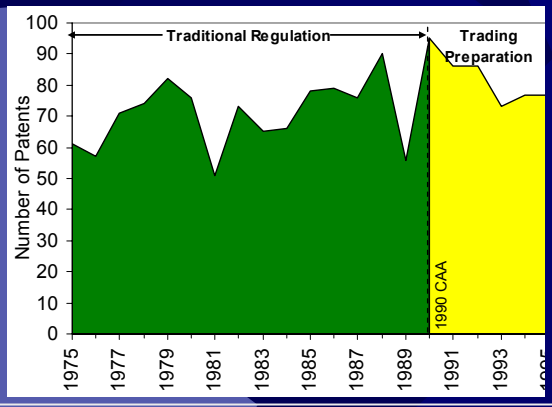
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

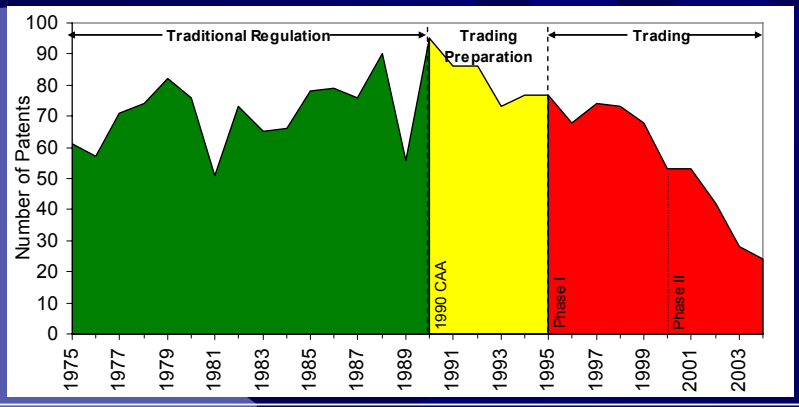
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

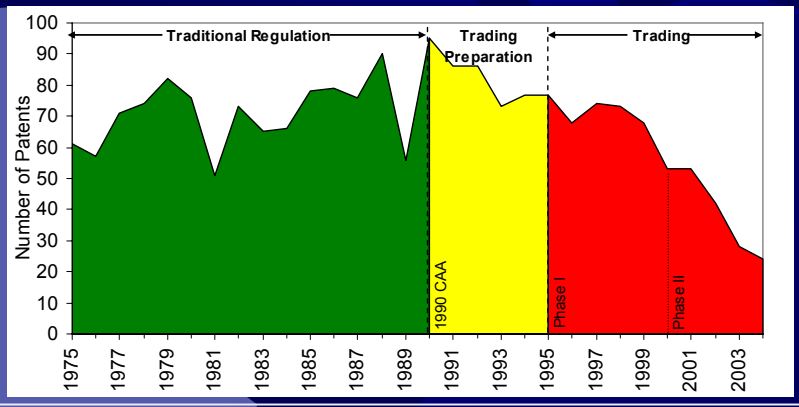
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

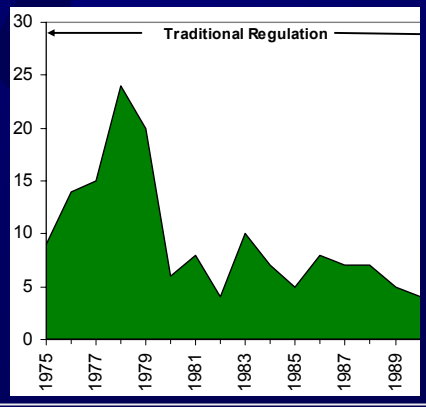
Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

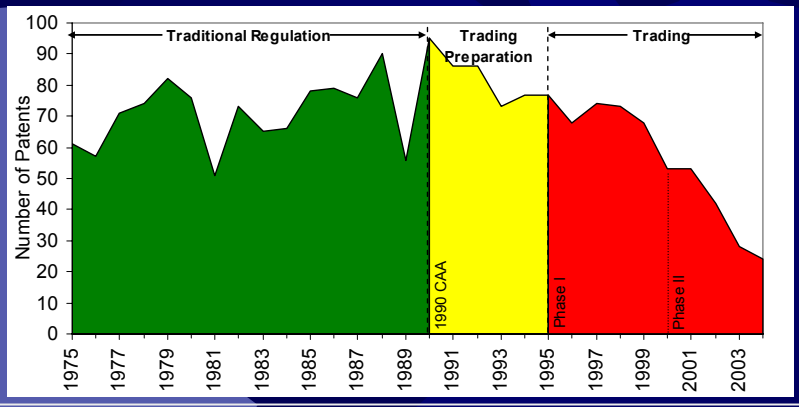
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

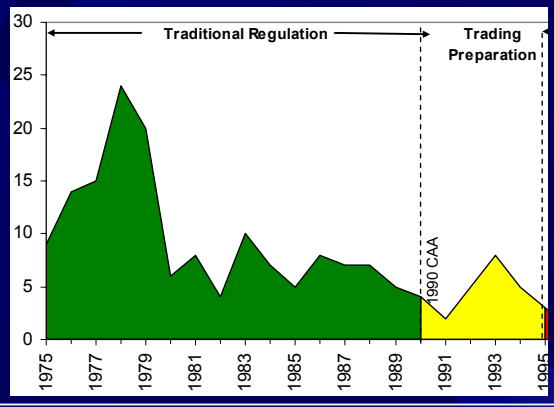
Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

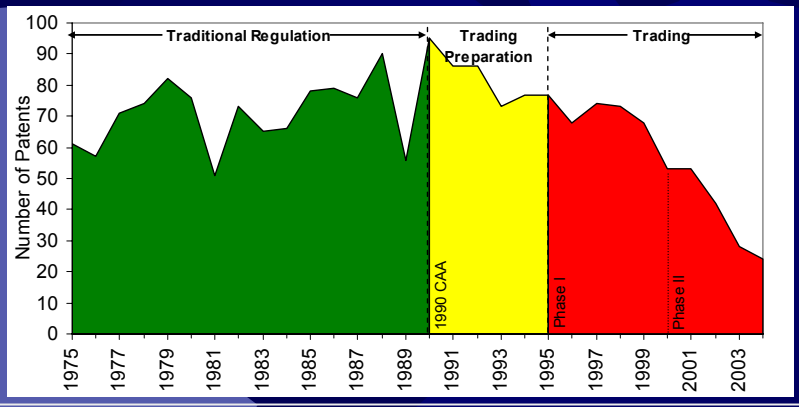
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

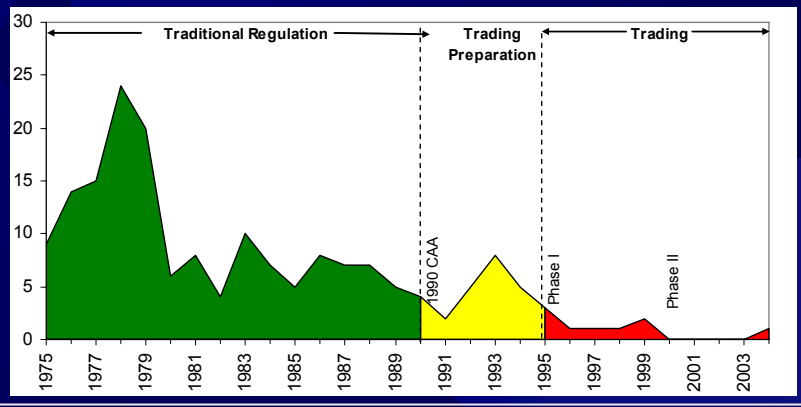
Trading

Invention along existing clean tech pathways

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

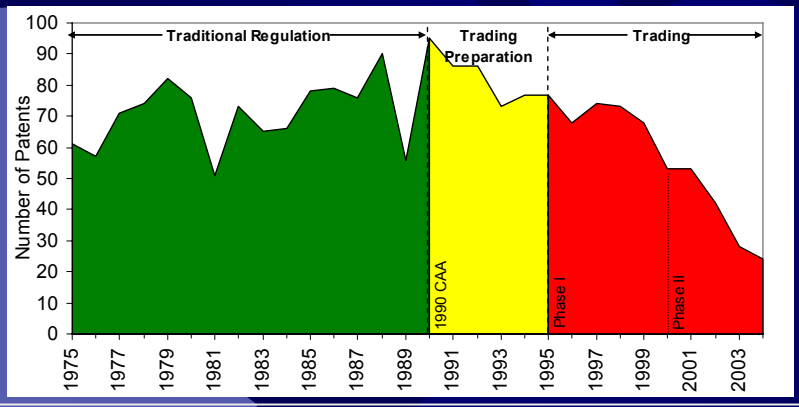
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

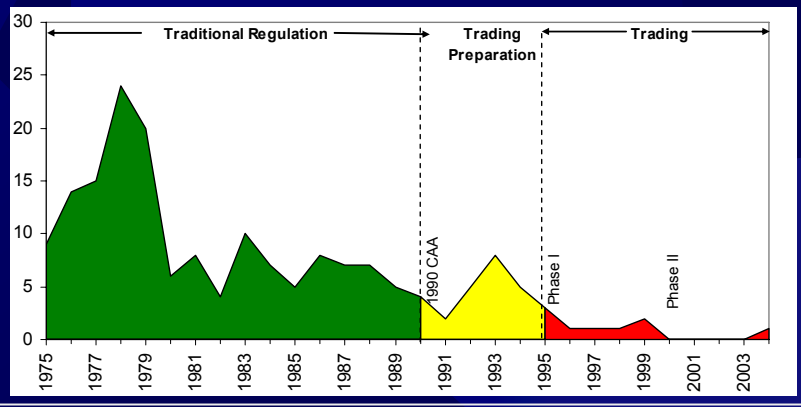
Trading

Invention along existing clean tech pathways

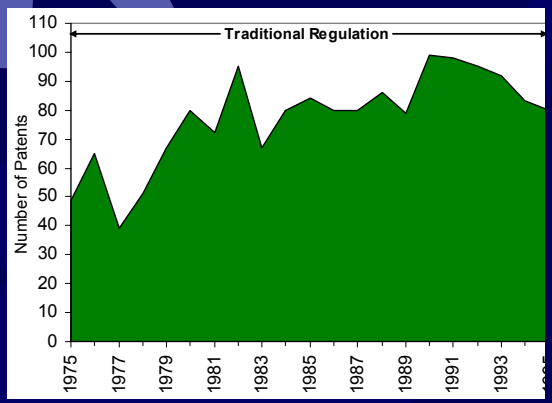
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification

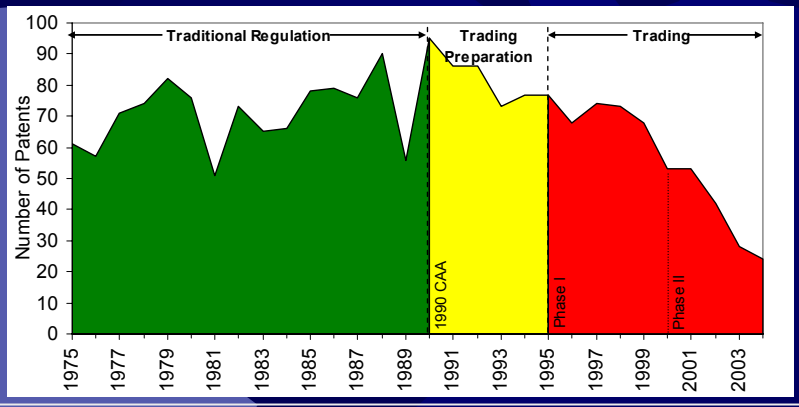
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

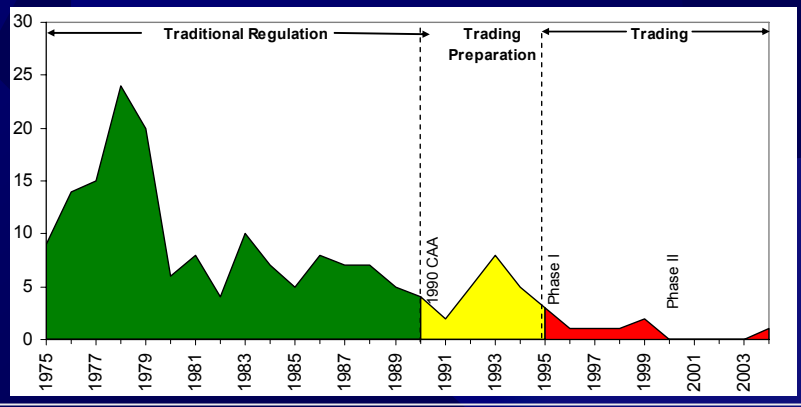
Trading

Invention along existing clean tech pathways

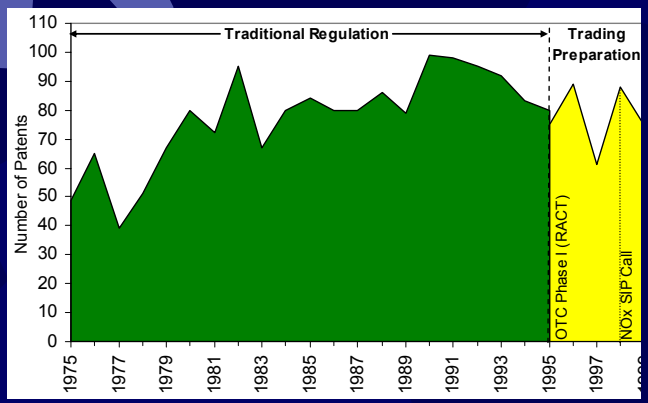
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification

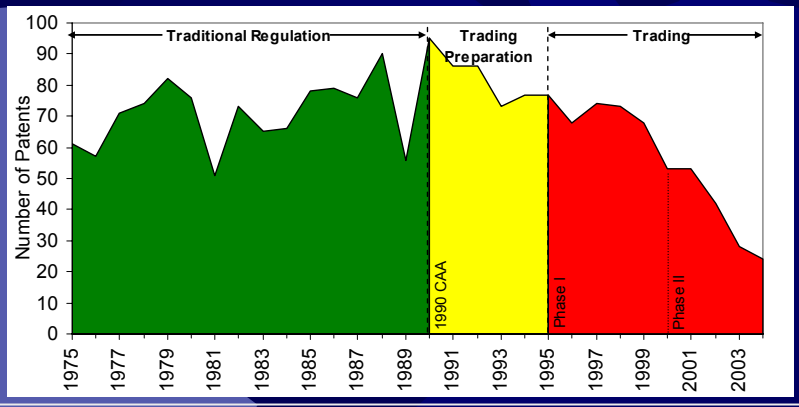
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

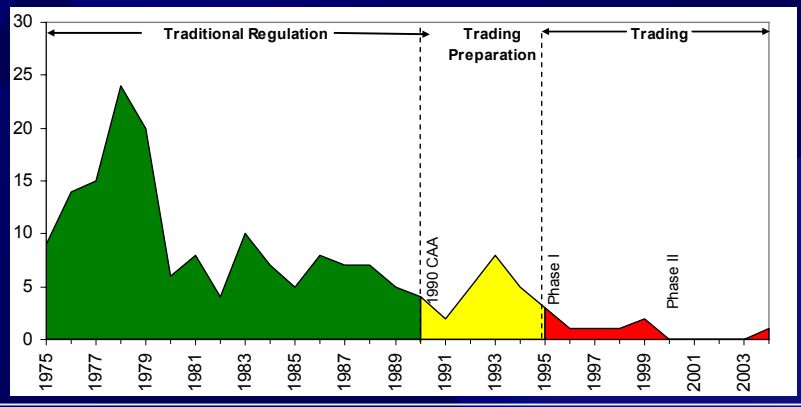
Trading

Invention along existing clean tech pathways

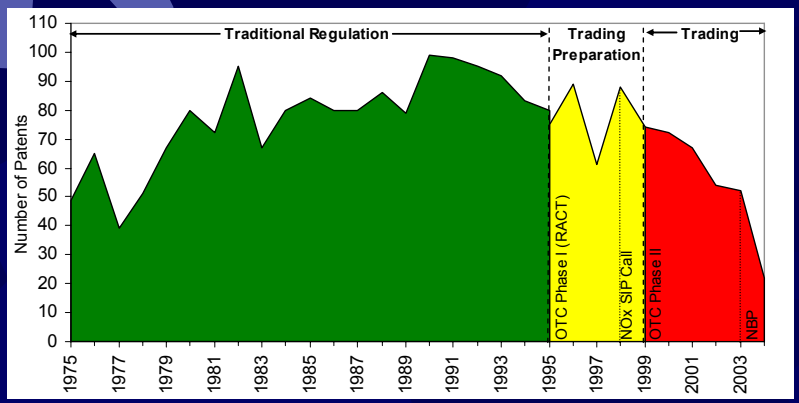
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification

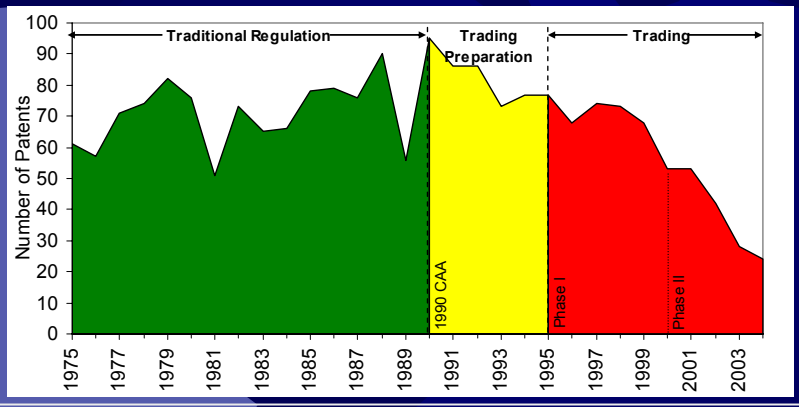
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

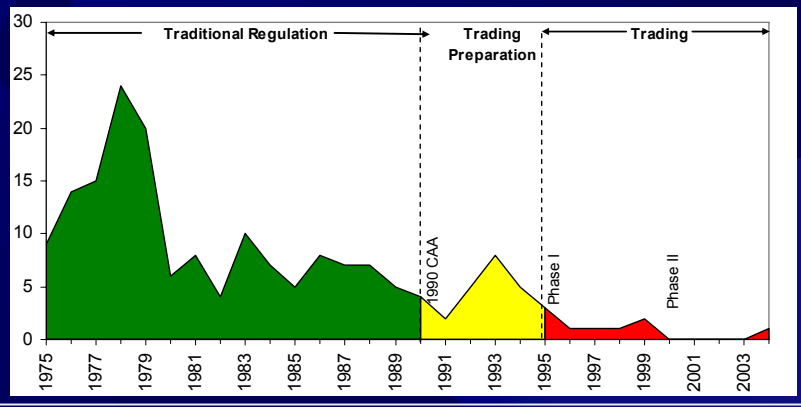
Trading

Invention along existing clean tech pathways

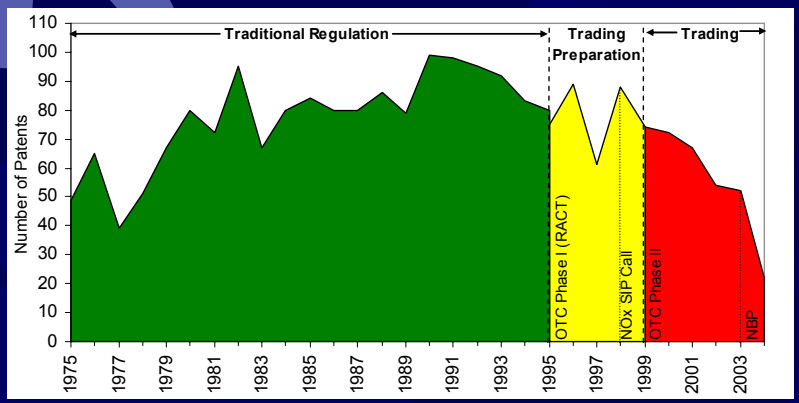
(a) Post-combustion SO_2 control



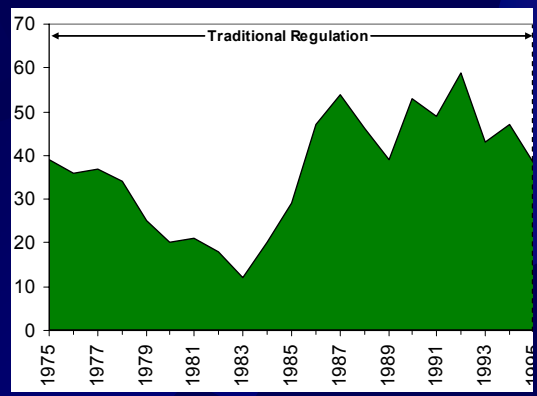
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



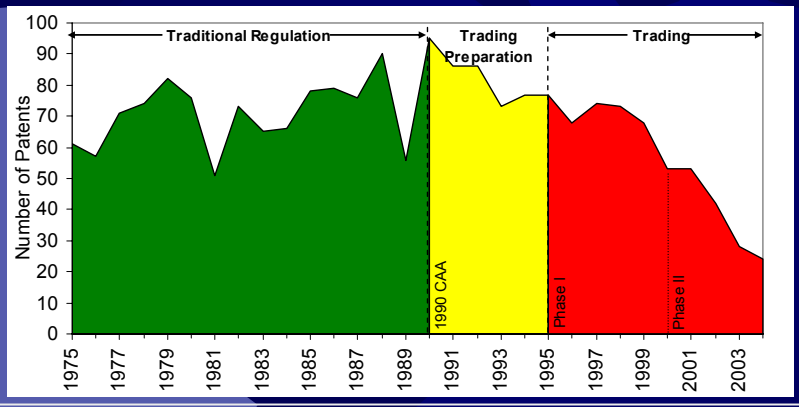
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

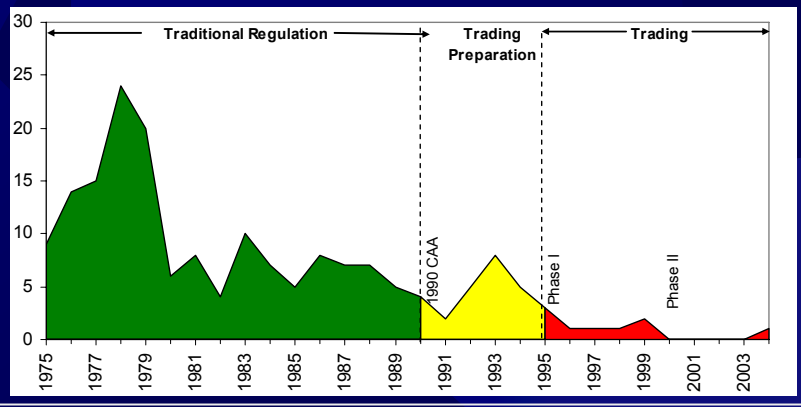
Trading

Invention along existing clean tech pathways

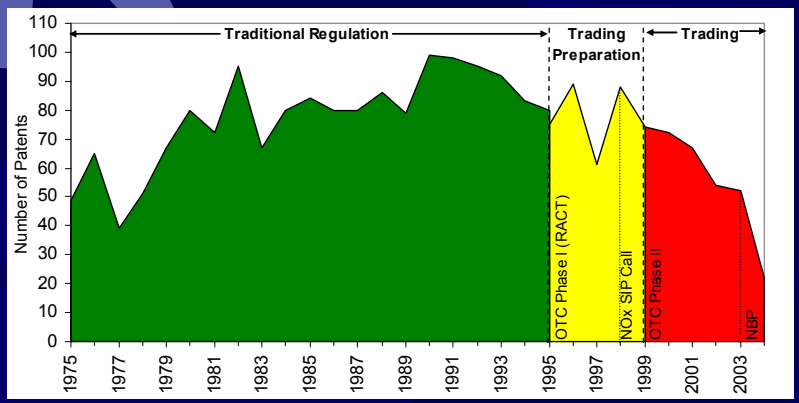
(a) Post-combustion SO_2 control



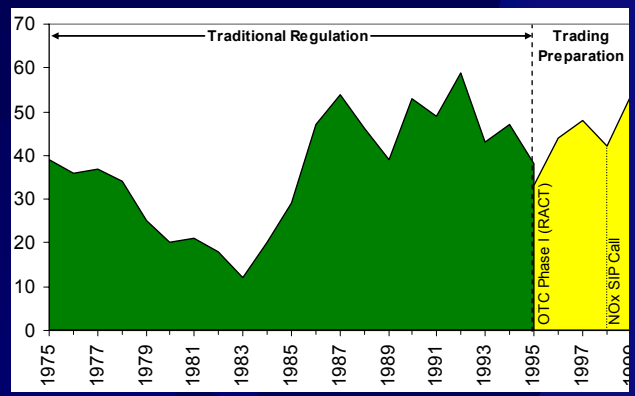
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



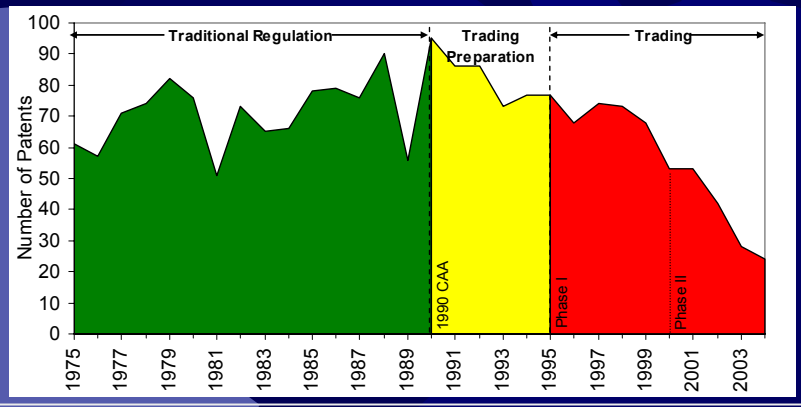
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

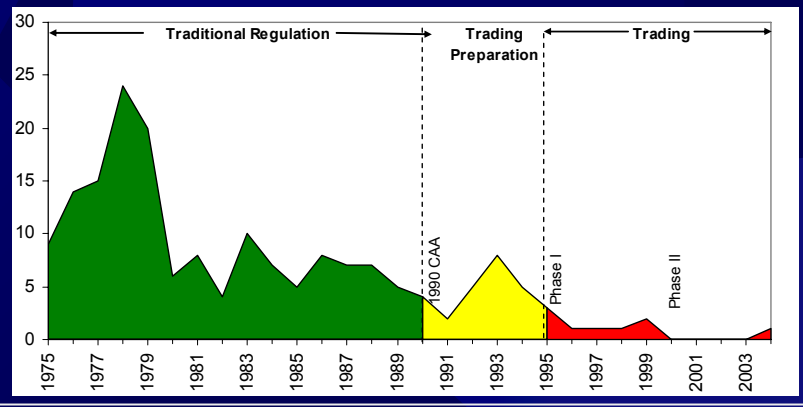
Trading

Invention along existing clean tech pathways

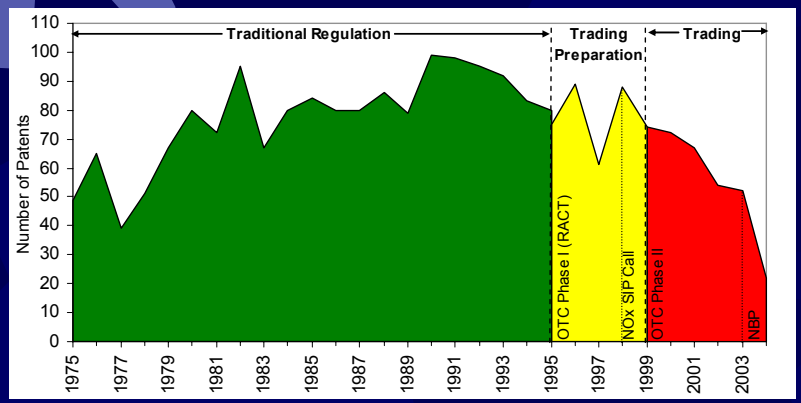
(a) Post-combustion SO_2 control



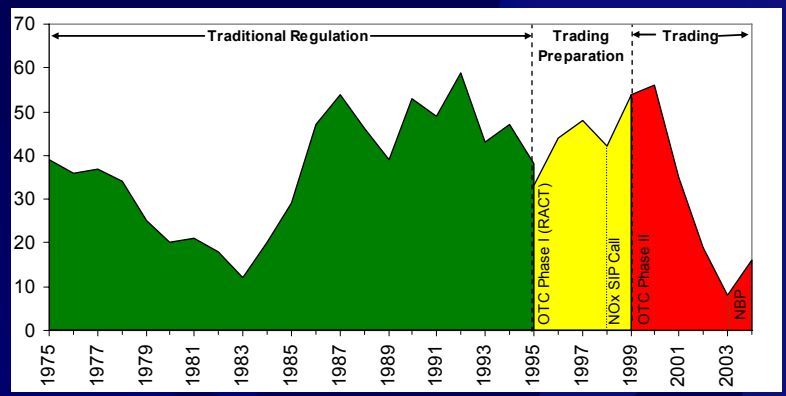
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



Traditional environmental regulation

Trading preparation (after passage, before actual prices)

Trading

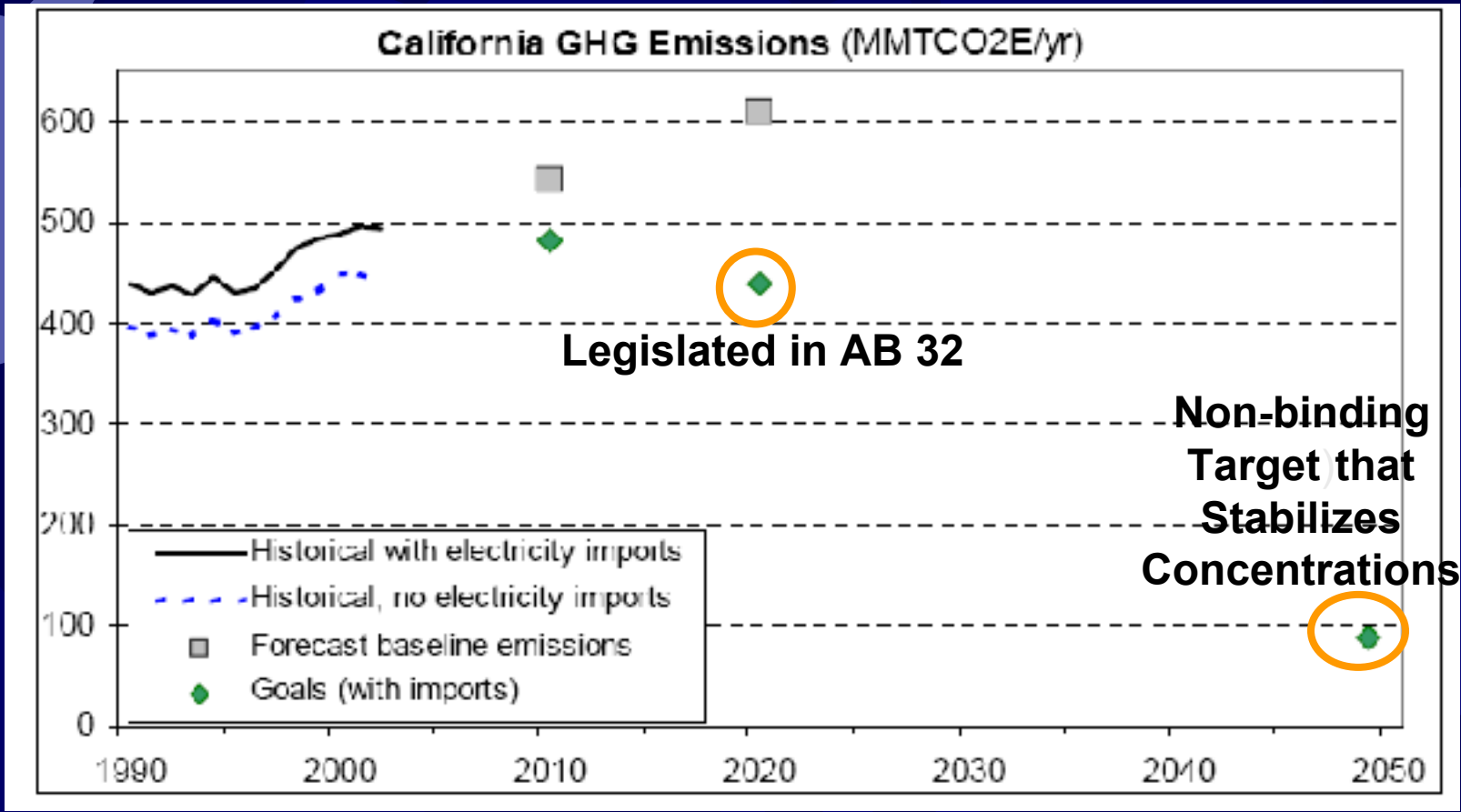
Discussion

Theory and these observations

- Theory posits that CTPs and emissions taxes incentivize polluting sources to exploit the full range of abatement channels available to them
  - Re: inventive activity, a plausible hypothesis is that developers faced with lower-than-expected allowance prices deemed technologies to be “good enough” for U.S. market conditions for the foreseeable future and diverted R&D funds elsewhere accordingly
  - Data limitations make this difficult to confirm

Likely importance of inventive activity to achieving climate stabilization - 1

- The “end point” implies a strong need for invention



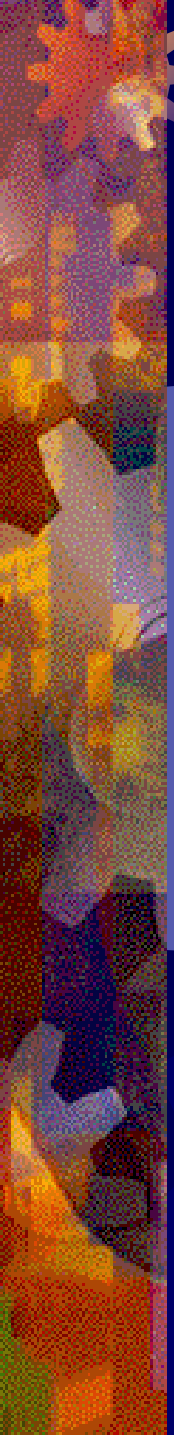
Source: Managing Greenhouse Gas Emissions in California, fig. 3-1

Likely importance of inventive activity to achieving climate stabilization

- The "starting point" re: existing abatement channels is arguably behind where it was for comparable options under Title IV and the OTC/NBP
  - Input substitution is unlikely to provide significant gains
  - No commercially available post-combustion control technologies for CO_2
  - Generation substitution through renewables still face significant cost and performance challenges
  - Output reduction available:
    - Could increase use of energy efficiency technologies and shift utilization to existing lower-emitting generation sources like nuclear power plants
  - CO_2 control has the unique abatement channel of emissions sinks

Thinking about policy design

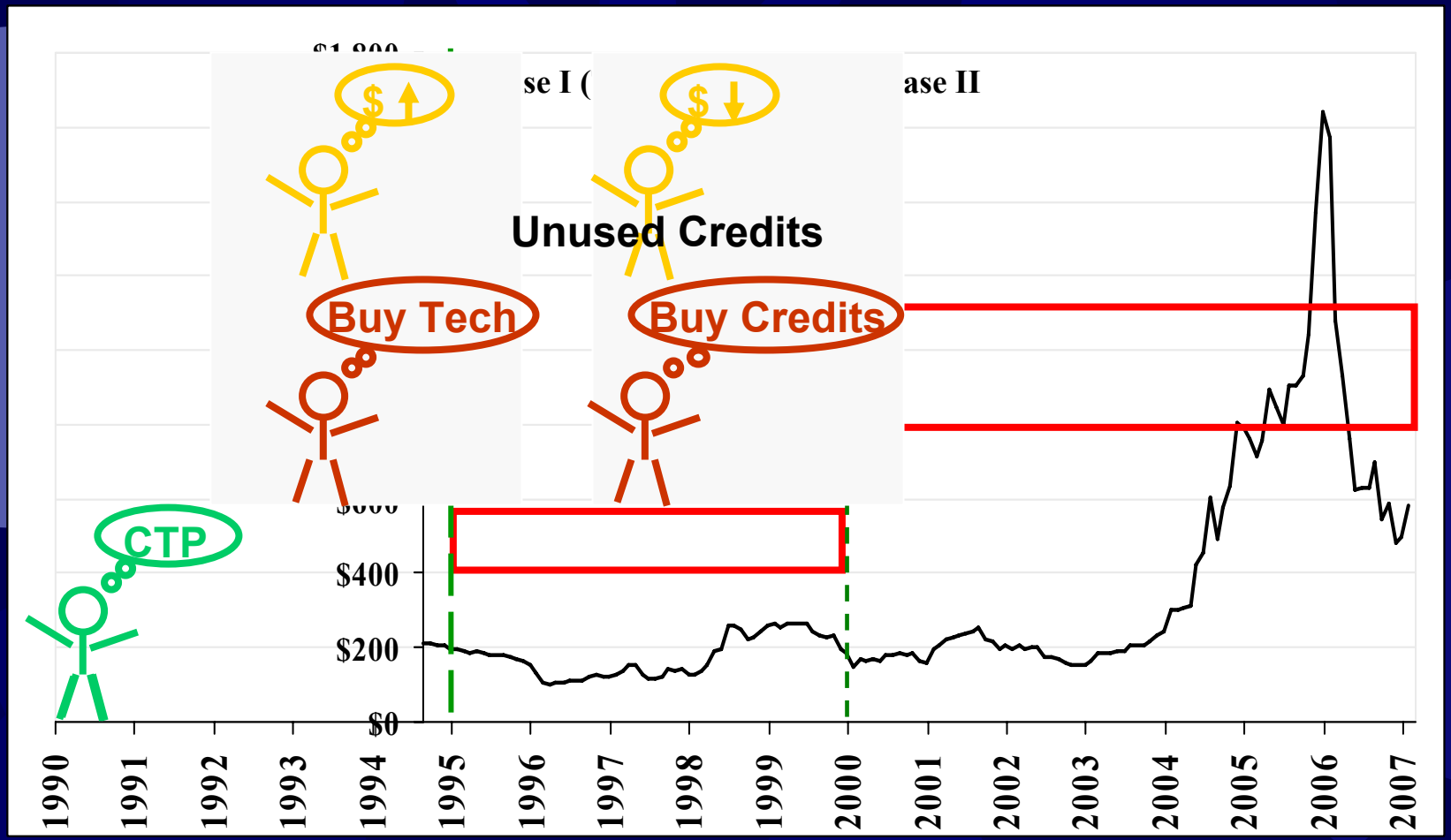
- Consider inventor expectations when setting caps and making rules for the allowance market
  - Price credibility important
- Complementary policies to a CTP
  - Focus on either reducing the costs of R&D or increasing the chances that technology in certain sectors will be deployed, thereby gaining the opportunity to improve from experience
  - Selection criteria should include the relative cost of emissions reductions and the certainty of sustaining the instrument over the long-term in order to maintain the incentives for invention



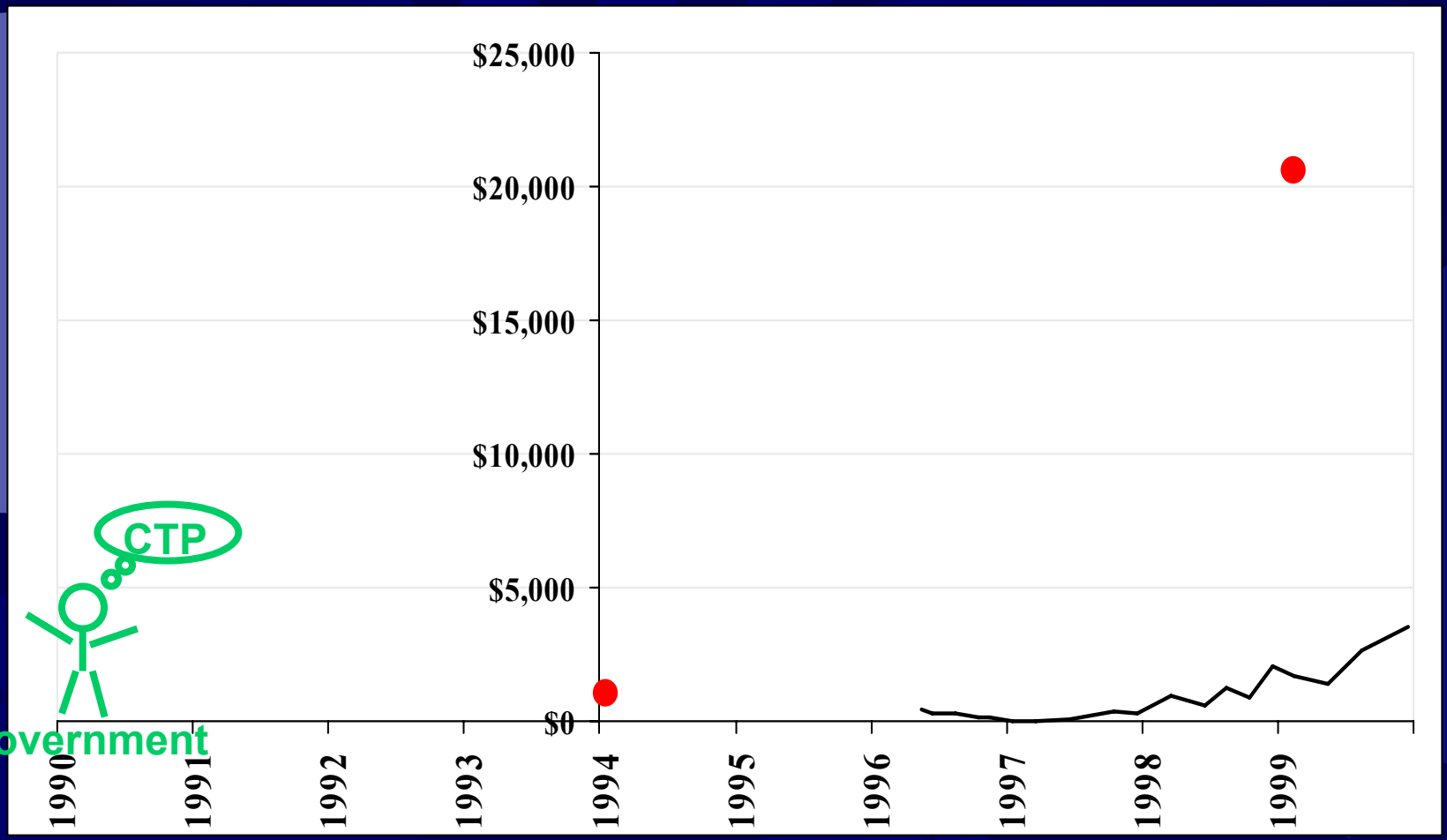
Backup slides

More on CTPs and Innovation

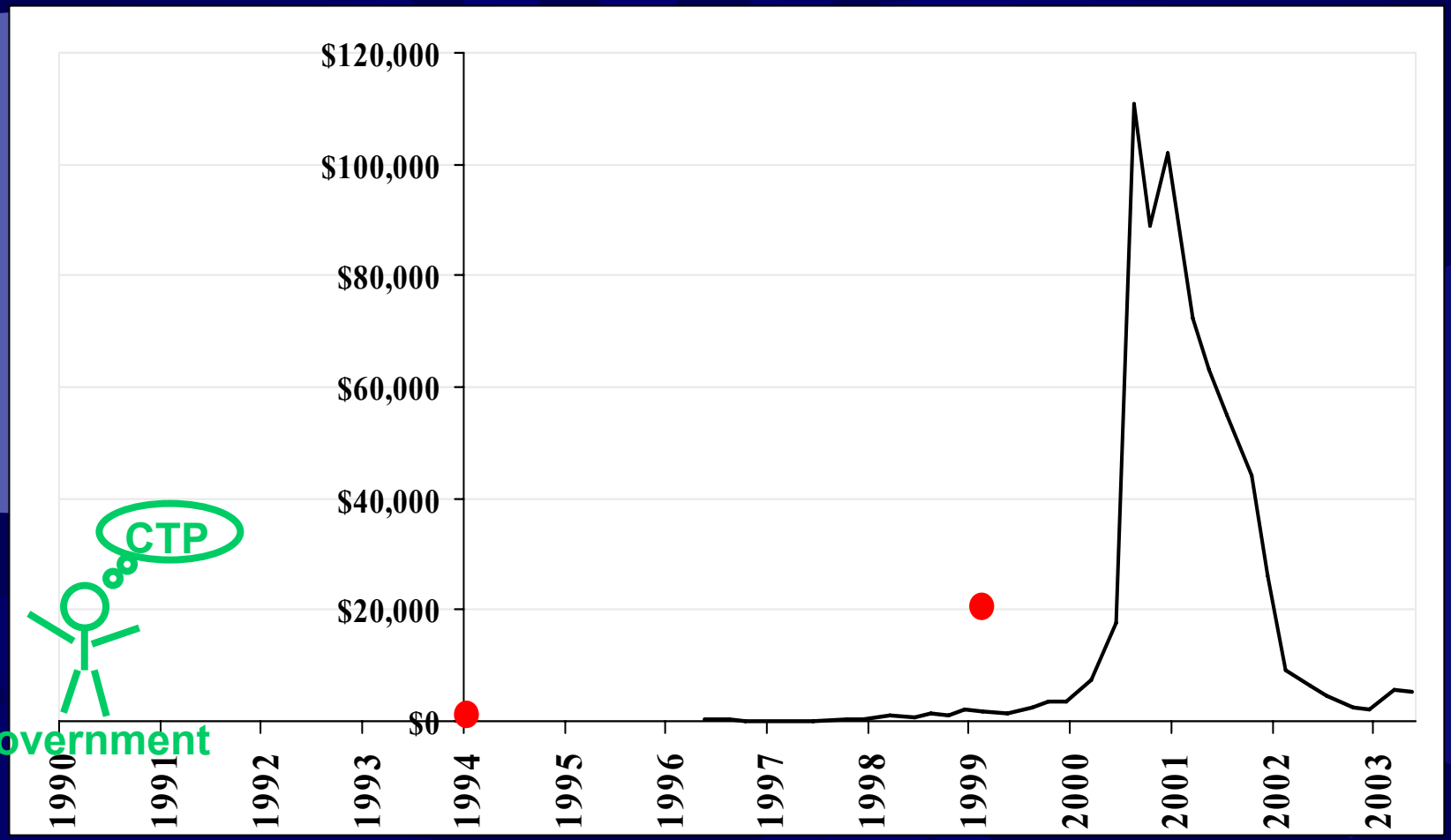
Title IV Prices ($/Ton SO_2)



NO_X RECLAIM Prices ($/Ton) - Lower than Expected



NO_X RECLAIM Prices ($/Ton) - California Electricity Crisis Unexpected



Could Play with Quantities

1. Start with a strict cap and initial allowance auction (use revenues for R&D)
2. Set regular intervals (5 years?) to modify the cap, but don't set exact levels when law is initially passed
    1. Allows you to adjust to climate science, technologies
    2. (Could revalue some of the banked allowances for similar effect)
3. Charge an independent board with the modifications

Preserves the advantages of a CTP while sustaining the market expectations of technology suppliers

Could Play with Prices

Safety Valve

Isn't this a carbon tax w/brokerage fees?

Symmetric Safety Valve

Could Play with Other Policies

- Public R&D funding?
  - Risky to count on sustaining high levels over time (politics, budget exigencies)
  - Involves government picking winners
- Public subsidy programs?
  - Similar risks
- Standards?
  - Not as risky re: lapsing
  - Not as much of a “pick winners” problem s R&D funding, subsidies
  - Arguably better for inventor market expectations:
    - More direct, predictable than CTP
    - Standards usually get stricter

A Timeline relevant to Clean Tech

Year	Climate Policy Events	Clean Tech Deals	Investment ($mil)
2001	U.S. pulls out of Kyoto Protocol	Unknown	Unknown
2002	CA AB1493 GHGs from mobile sources	Unknown	Unknown
2005	NE States announce RGGI agreement CA Executive Order on GHGs, CA AB 1007 on alternative fuels	100	532.7
2006	CA AB32 Film: An Inconvenient Truth Hurricane Katrina	180	1,779.6
2007	Western Climate Initiative launched Midwestern Regional GHG Reduction Accord launched	168	2,604.9
2008	Florida Climate Protection Act Financial Collapse Barack Obama elected president	Too soon	Too soon

Sources: Pew Center on Global Climate Change, NVCA/Thomson Financial

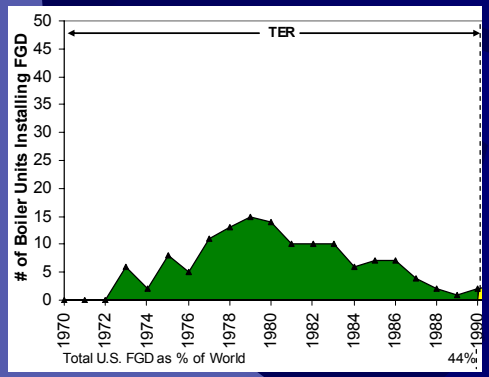
Will it Happen in Climate CTPs?

Only one operating so far: EU Emissions Trading Scheme

- Prices (€/Ton) lower than Expected

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

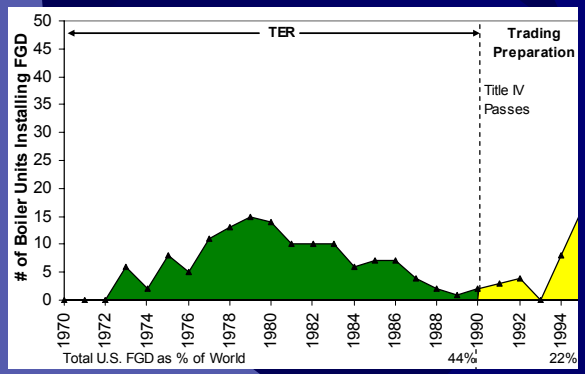
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

Trading

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

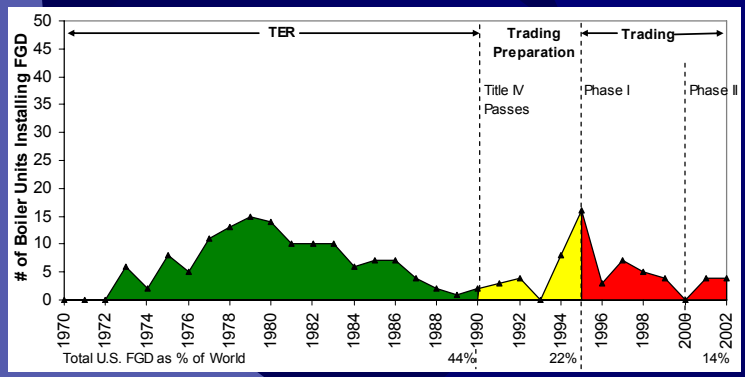
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

Trading

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control

(c) Post-combustion NO_x control

(d) NO_x combustion modification

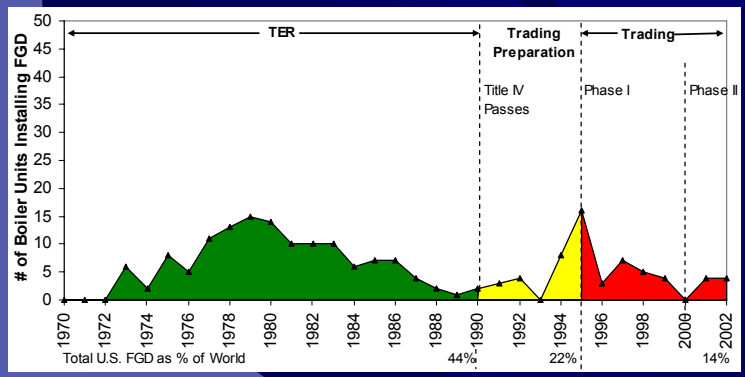
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

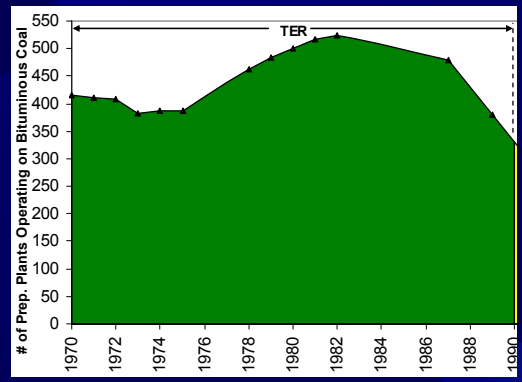
Trading

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

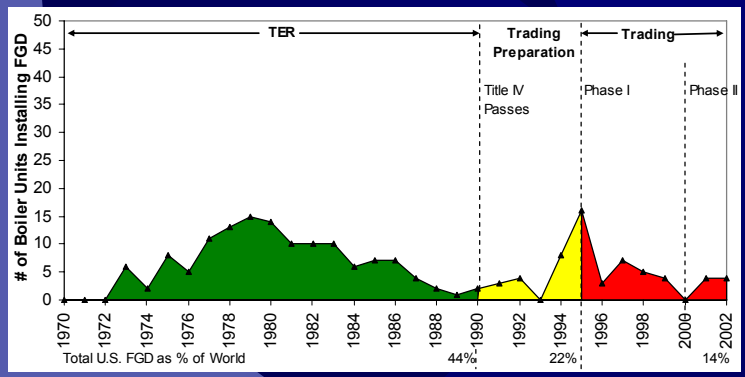
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

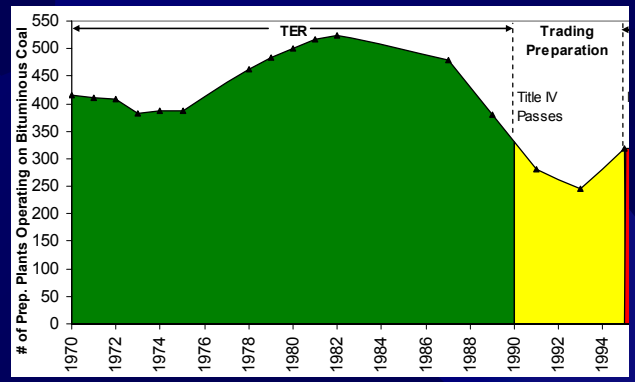
Trading

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

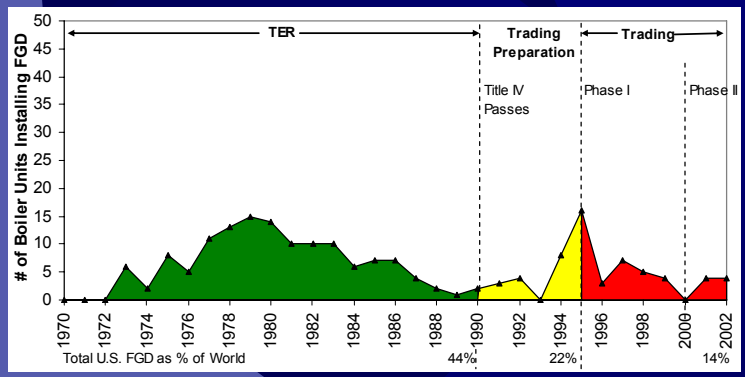
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

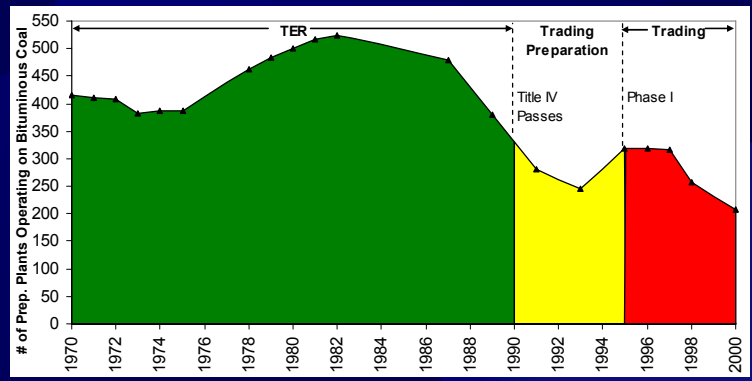
Trading

Adoption of existing technologies

(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control

(d) NO_x combustion modification

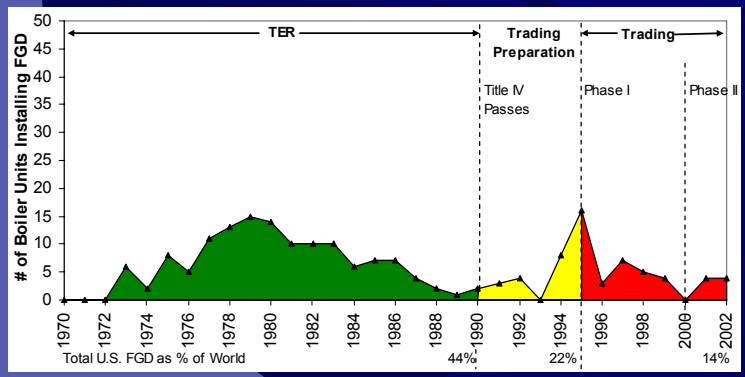
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

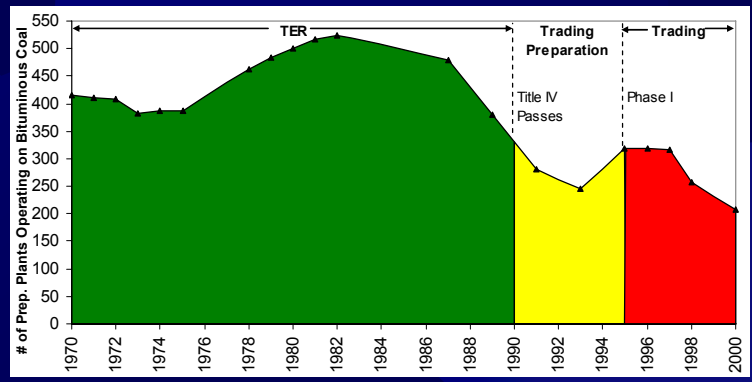
Trading

Adoption of existing technologies

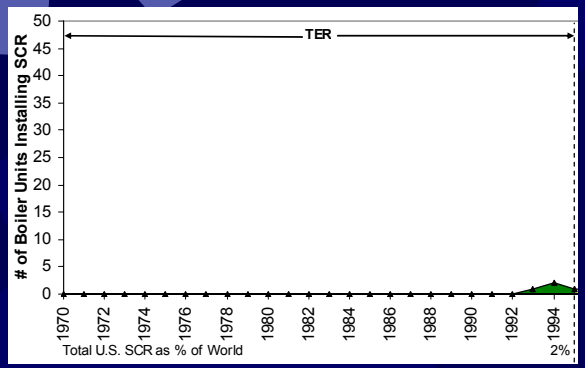
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



Traditional environmental regulation

Trading preparation (after passage, before actual prices)

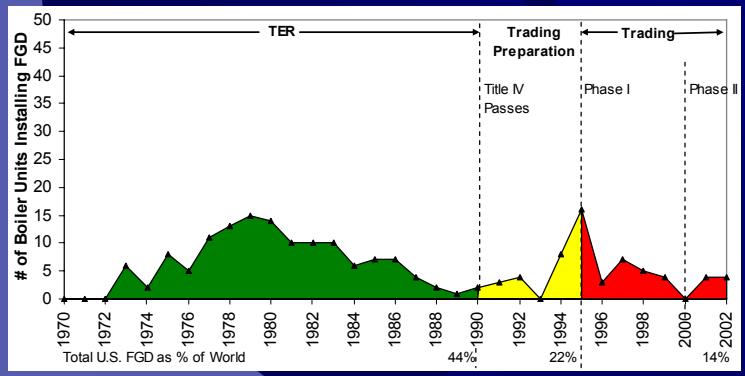
Trading

(d) NO_x combustion modification

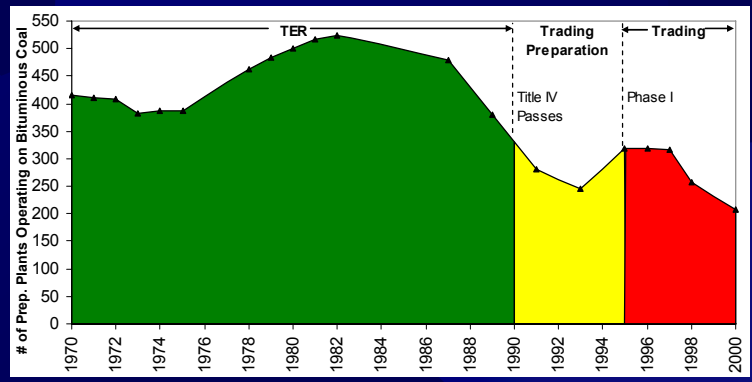
Please do not cite/distribute

Adoption of existing technologies

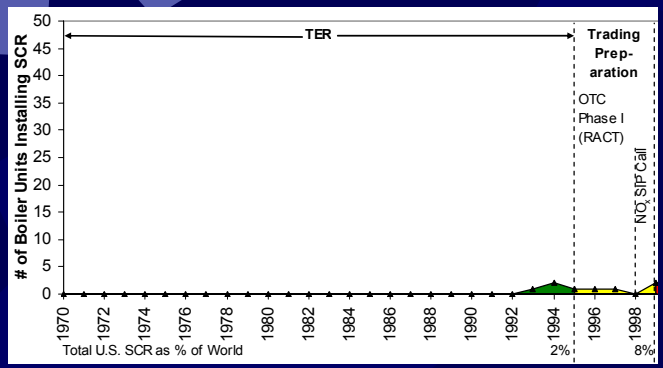
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification

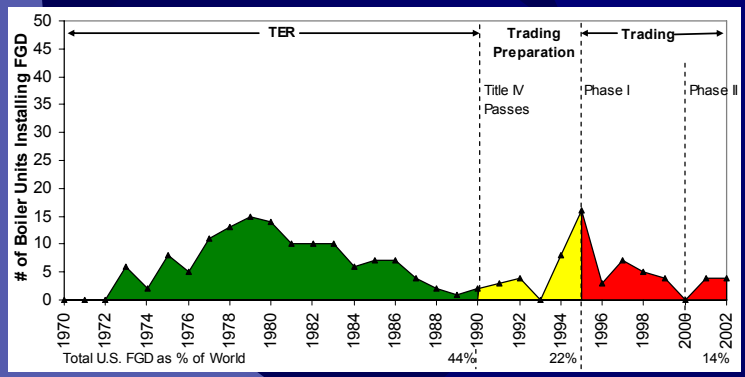
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

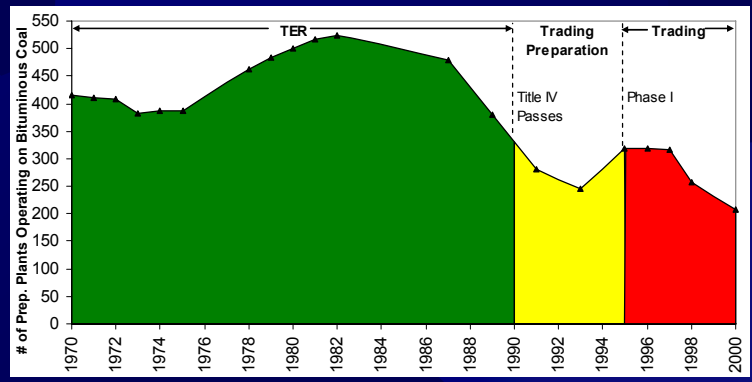
Trading

Adoption of existing technologies

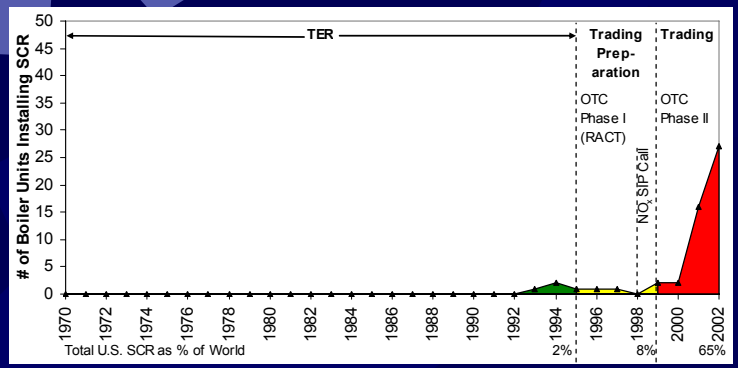
(a) Post-combustion SO_2 control



(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification

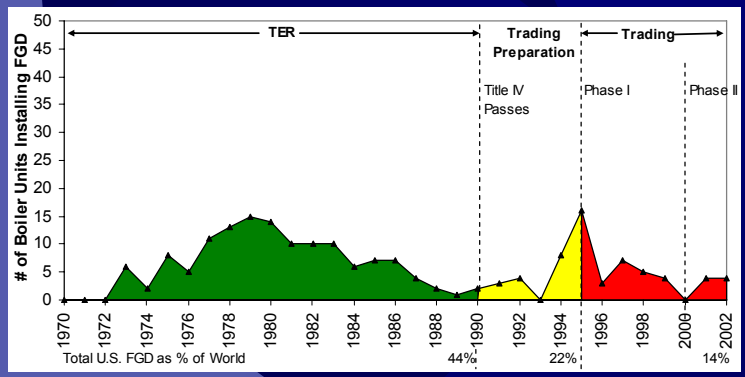
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

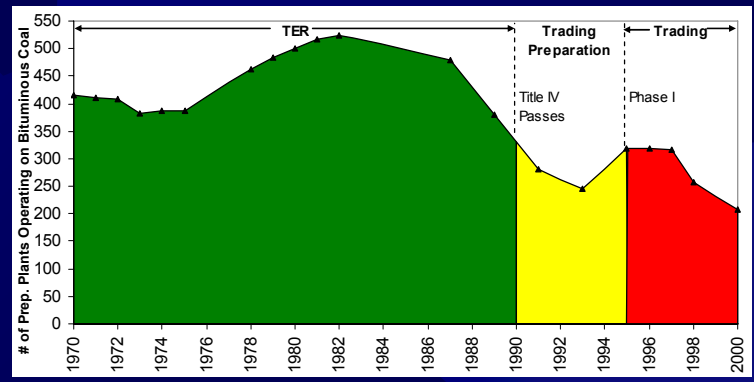
Trading

Adoption of existing technologies

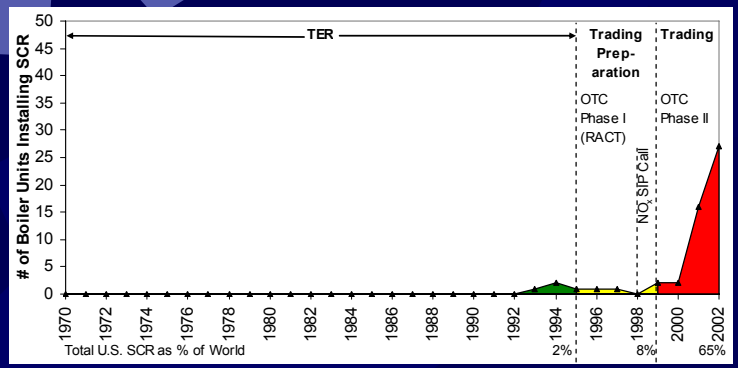
(a) Post-combustion SO_2 control



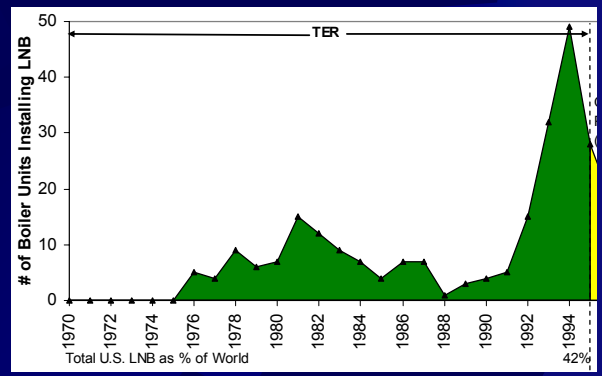
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



Traditional environmental regulation

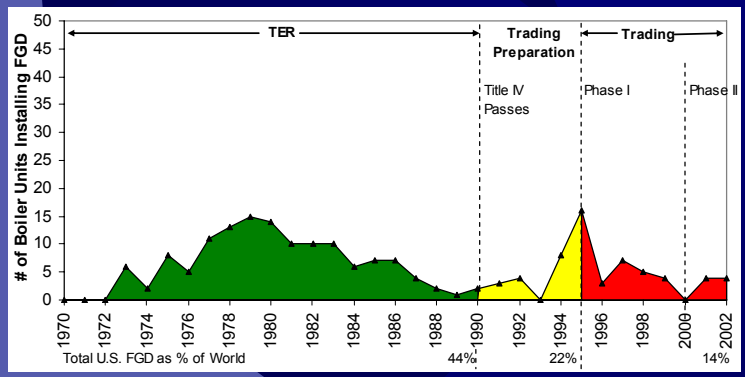
Trading preparation (after passage, before actual prices)

Trading

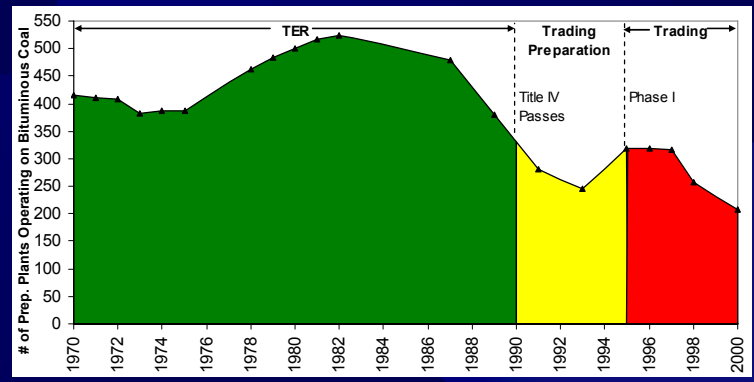
Please do not cite/distribute

Adoption of existing technologies

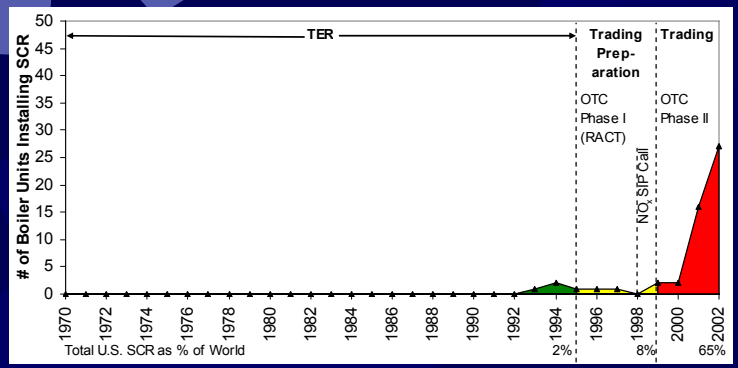
(a) Post-combustion SO_2 control



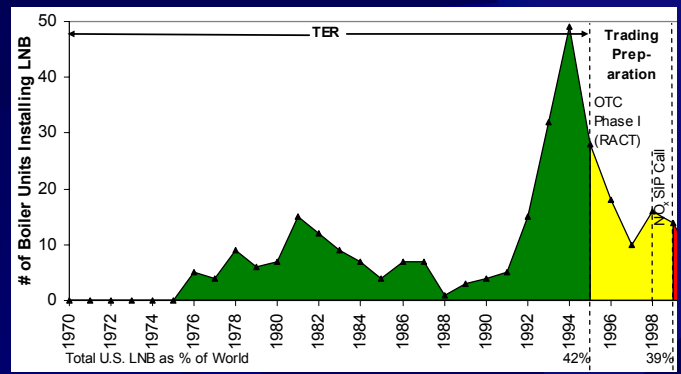
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



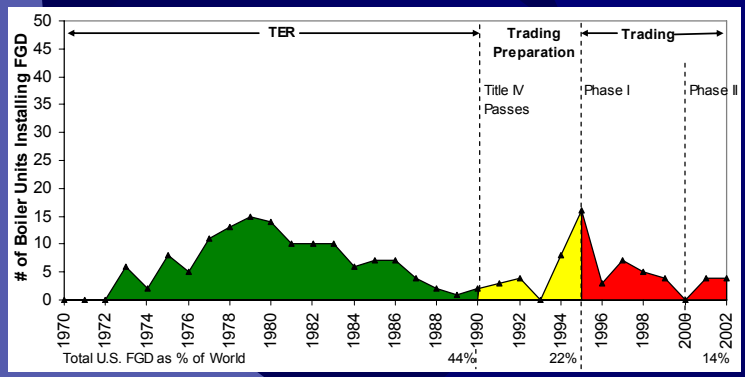
Traditional environmental regulation

Trading preparation (after passage, before actual prices)

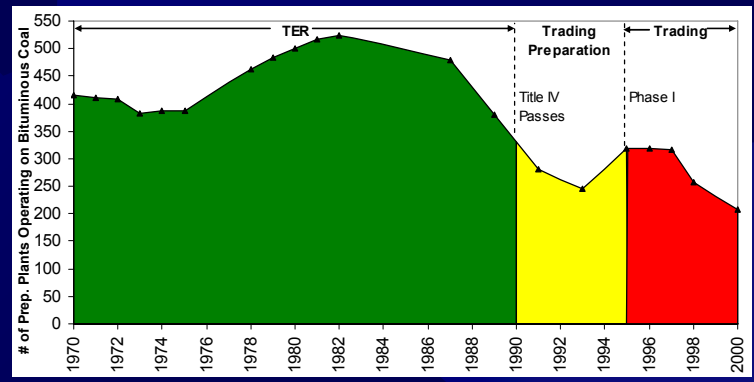
Trading

Adoption of existing technologies

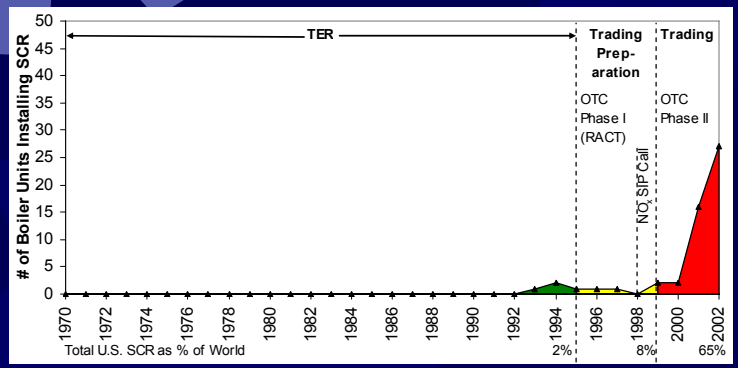
(a) Post-combustion SO_2 control



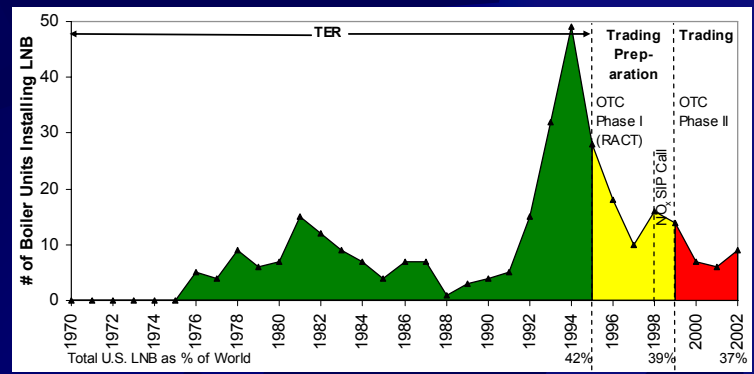
(b) Pre-combustion SO_2 control



(c) Post-combustion NO_x control



(d) NO_x combustion modification



Traditional environmental regulation

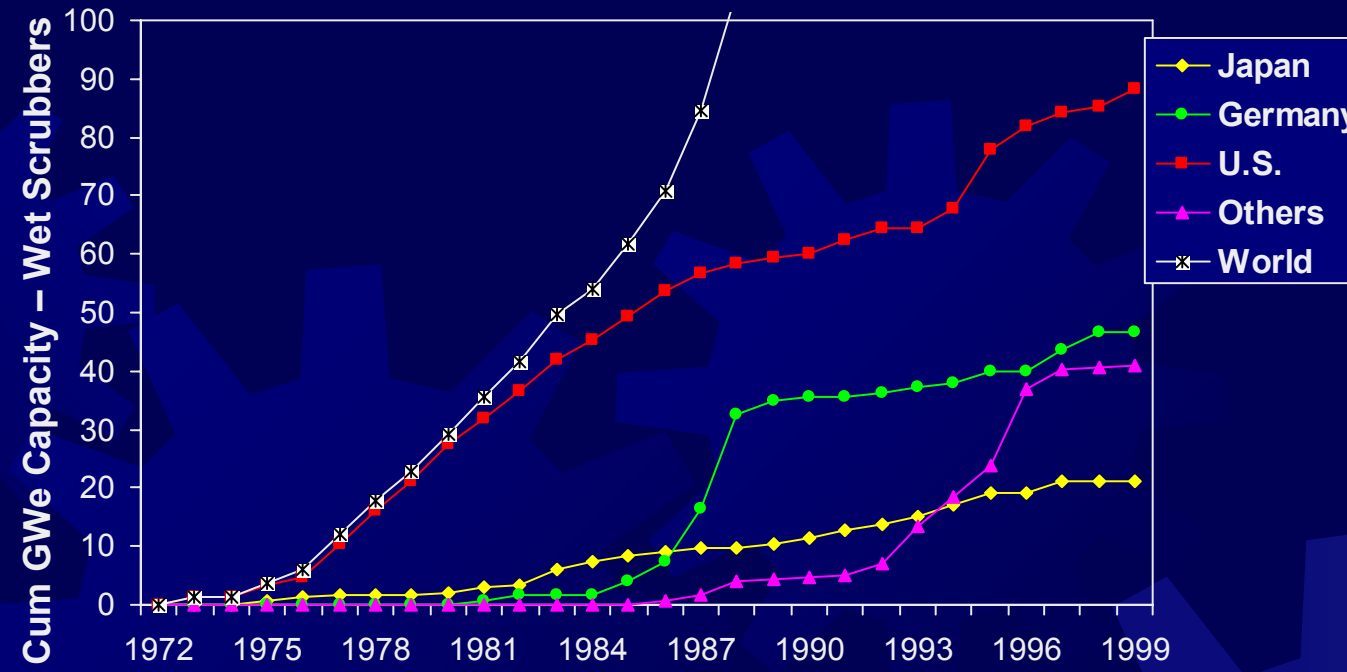
Trading preparation (after passage, before actual prices)

Trading

FGD

U.S. market results from stringent U.S. standards

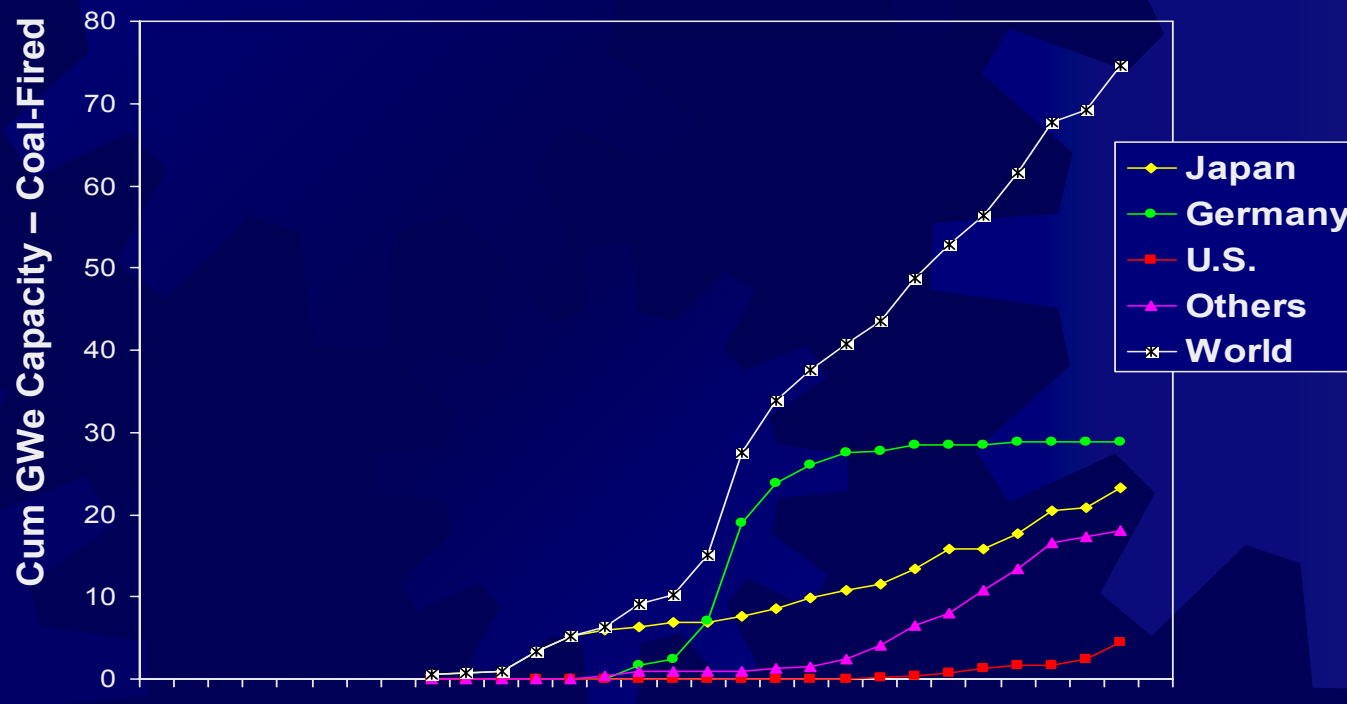
Early 1970s EPA says FGD is demonstrated enough to be basis of NSPS



SCR

U.S. market results from stringent U.S. standards

Late 1970s EPA says SCR not demonstrated enough to be basis of NSPS



Several unanswerable questions

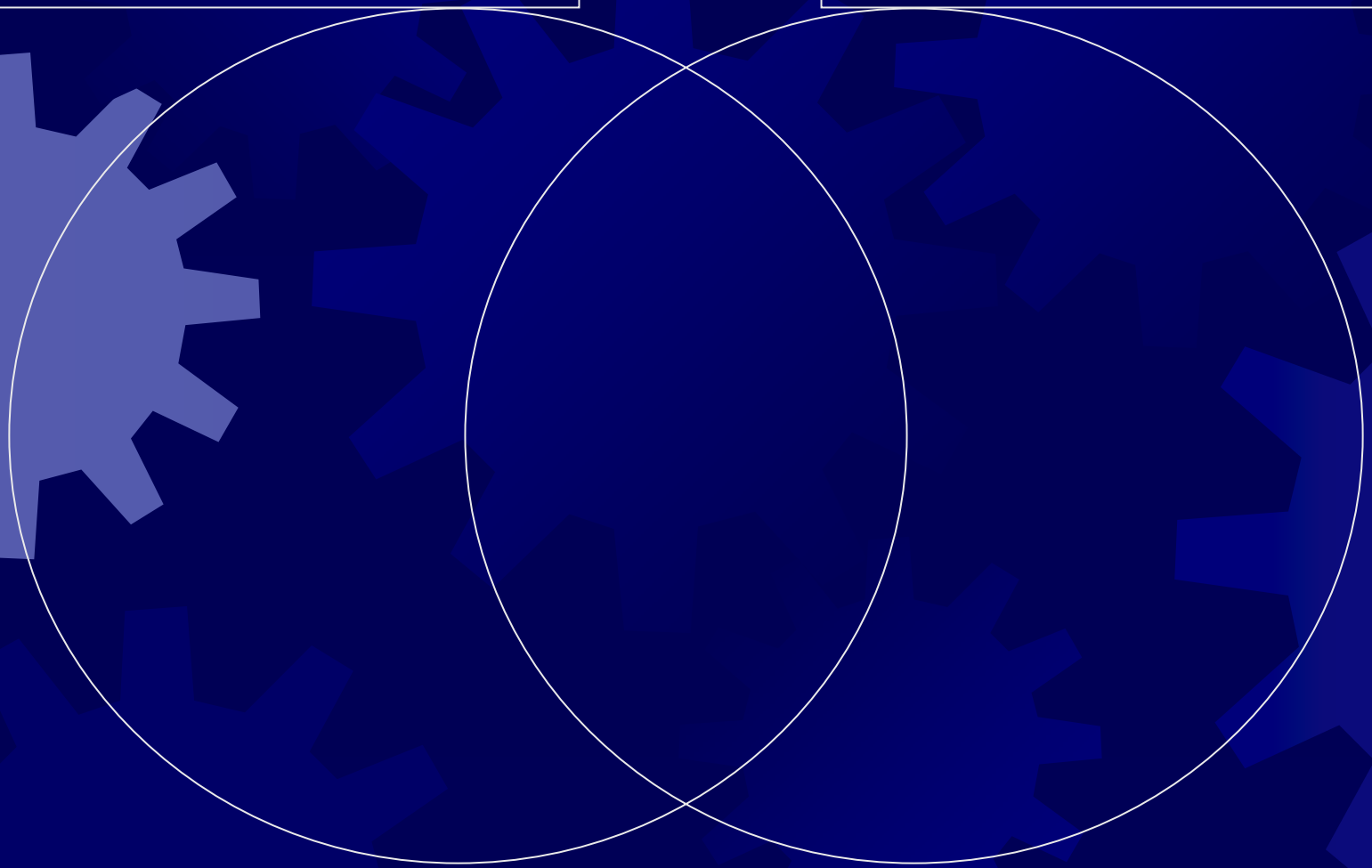
- Were expensive, high performance technologies which achieved commercially acceptable reliability, performance, and cost over a long period of time and contributed to the success of these CTPs, actually necessary for environmental goals?
- If so, would CTPs with no prior direct regulatory policy have adequately encouraged the development of these technologies?
- Would the stringency of emissions caps have been the same under Title IV and the OTC/NBP had these technologies not been commercially available?

Introduction to my research program and approach

Research Program

Energy/Environmental Policy

Innovation



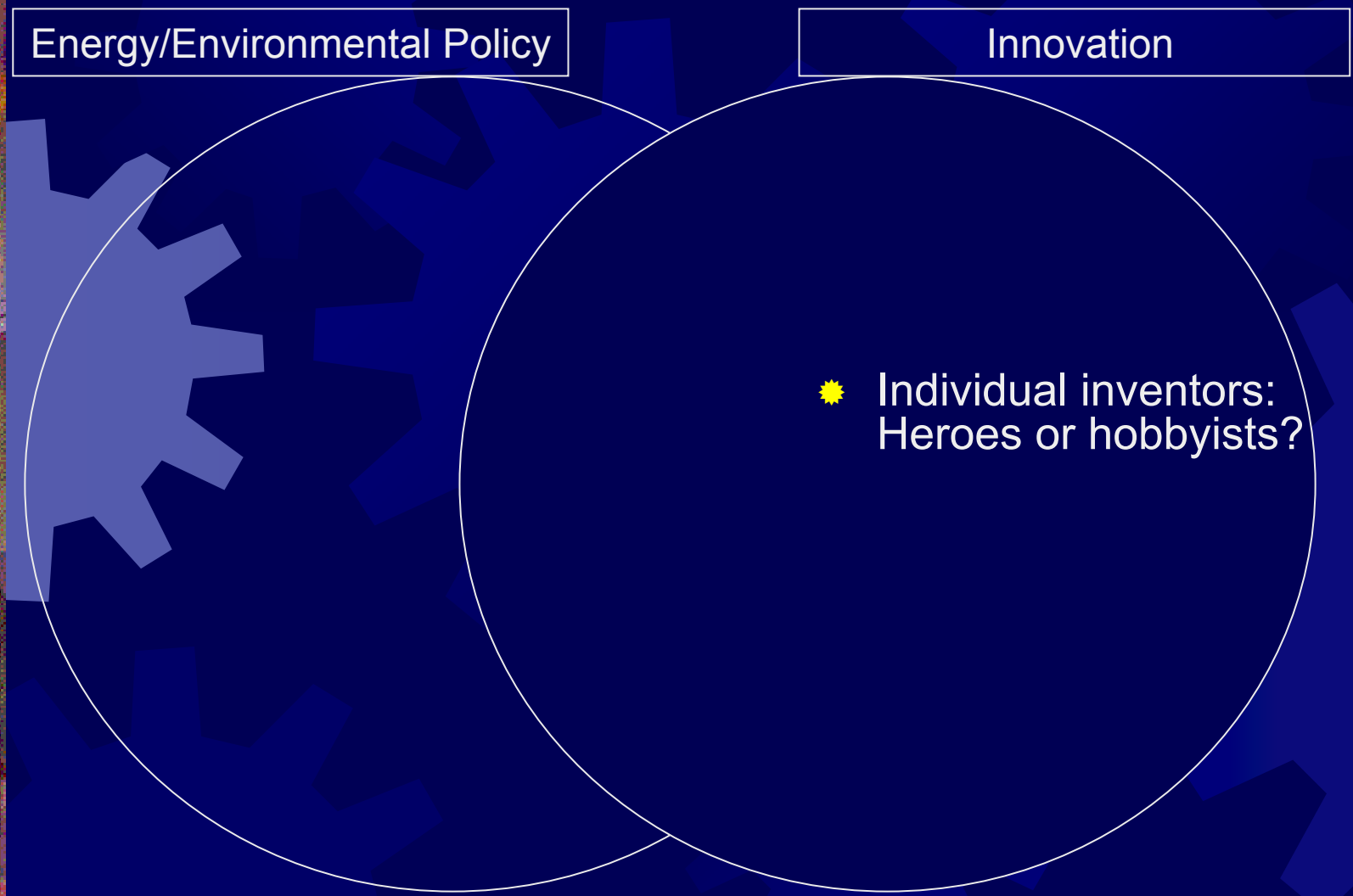
Research Program

Energy/Environmental Policy

Innovation

- Nanotechnology EHS
  - R&D priorities
  - Muddling through
- Risks of nuclear waste vs. CCS
- Sustainable packaging

Research Program



- Individual inventors: Heroes or hobbyists?

Research Program

Energy/Environmental Policy

Innovation

- 2050 goals of up to 80% reduction in GHG emissions from 1990 levels are our current best guess for safety
- Meeting these will require the diffusion through many economic sectors of both existing & new technologies
- Designing policies that support diffusion and invention with an eye to commercialization is *at least* a smart hedge…
- Need for systematic policy evaluation on the metric of support for innovation

Research approach

- Important to know theory but appreciate that it is an over-simplification of reality
- Important to understand constraints imposed by technology, institutions
- Bottom-up study of environment and innovation can lead to more practical policy approaches
  - Can only be done by bridging disciplines and employing complementary analyses

Data and analytical approaches used to date

- Econometric analysis of patenting activity
- Network analysis of researchers
- Compilation and analysis of R&D activity, particularly by the public sector
- Compilation and analysis of cost and performance trends as related to cumulative operating experience (experience & learning curves)
- Interviews with influential experts
- Integrated assessment modeling
- Life-cycle analysis
- …

Research Purpose	Technologies Involved

Research Purpose	Technologies Involved
Learning from experience with innovation and traditional environmental regulation	
Learning from experience with innovation and renewable energy policies	
Learning from experience with innovation and cap-and-trade programs	
Learning from experience with innovation and adaptive management in technology-forcing policy • California's low-emissions vehicle (LEV) program and its zero-emissions vehicle (ZEV) sub-program	

Research Purpose	Technologies Involved
Learning from experience with innovation and traditional environmental regulation	
Learning from experience with innovation and renewable energy policies	
Learning from experience with innovation and cap-and-trade programs	
Learning from experience with innovation and adaptive management in technology-forcing policy • California's low-emissions vehicle (LEV) program and its zero-emissions vehicle (ZEV) sub-program	
Improving integrated assessment modeling re: technological change	
Highlighting issues with framing the independent variable of policy as technology-push/demand-pull	
Exploring the relationship between public R&D and patenting activity	
Highlighting role & policy implications of individual inventors in clean technology	

Research Purpose	Technologies Involved
Learning from experience with innovation and traditional environmental regulation	Sulfur dioxide (SO_2) control technologies
Learning from experience with innovation and renewable energy policies	Wind, photovoltaics (PV), solar thermal electric (STE), and solar water heating (SWH)
Learning from experience with innovation and cap-and-trade programs	SO_2 and nitrogen oxide (NO_x) control technologies
Learning from experience with innovation and adaptive management in technology-forcing policy • California's low-emissions vehicle (LEV) program and its zero-emissions vehicle (ZEV) sub-program	Automotive emissions controls, battery-electric vehicles, hybrid-electric vehicles, and fuel-cell vehicles
Improving integrated assessment modeling re: technological change	SO_2, NO_x, carbon capture and storage techology (CCS)
Highlighting issues with framing the independent variable of policy as technology-push/demand-pull	PV, STE, SWH
Exploring the relationship between public R&D and patenting activity	
Highlighting role & policy implications of individual inventors in clean technology	Wind, PV, STE, SWH

Research Purpose	Technologies Involved
Learning from experience with innovation and traditional environmental regulation	Sulfur dioxide (SO_2) control technologies
Learning from experience with innovation and renewable energy policies	Wind, photovoltaics (PV), solar thermal electric (STE), and solar water heating (SWH)
Learning from experience with innovation and cap-and-trade programs	SO_2 and nitrogen oxide (NO_x) control technologies
Learning from experience with innovation and adaptive management in technology-forcing policy • California's low-emissions vehicle (LEV) program and its zero-emissions vehicle (ZEV) sub-program	Automotive emissions controls, battery-electric vehicles, hybrid-electric vehicles, and fuel-cell vehicles
Improving integrated assessment modeling re: technological change	SO_2, NO_x, carbon capture and storage techology (CCS)
Highlighting issues with framing the independent variable of policy as technology-push/demand-pull	PV, STE, SWH
Exploring the relationship between public R&D and patenting activity	
Highlighting role & policy implications of individual inventors in renewable energy	Wind, PV, STE, SWH

Thoughts from other cases

Case studies and their role in debates on policy and innovation

- Not as prominent as theoretical and econometric studies, but a lot of micro-lessons
- Authors to consider:
  - Nicholas Ashford (1985 paper)
  - Rene Kemp (1997 book)
  - David Wallace (1995 book)
  - Vicki Norberg-Bohm papers
  - Martin Janicke & Klaus Jacob (2004 book)

Clean Technology Strategies: Cases

- Traditional Power Generation
  - Control Emissions
    - Pre-Combustion: Fuel Switching/Cleaning
    - During Combustion: Modifications/additives
    - Post-Combustion: Pollution Control
  - Reduce Power Demand
    - More Efficient End-Use Technologies
    - More End-Use Technologies Ind. of Fossil Fuels
- Alternative Power Generation
  - Centralized
  - Distributed

SO_2 & NO_x* control

Solar water heating

Large-scale wind power, solar thermal electricity

Photovoltaics

* Pre-combustion not a factor in NOx control situation.

Thoughts on regulatory target-setting

- Costs relate to predictions of the technology
  - Issues of information asymmetry
    - How to know the status of the technology in a context of antagonistic legalism?
  - Predicting the outcomes of innovation not easy
- Stringency of regulation shapes technological pathways

Technology-forcing is tricky

- Ambitious targets that off-the-shelf technology can't achieve
  - "Steamships vs. sailboats" issue (disruptive vs. cumulative incremental innovation)
  - Issue of technological neutrality
- What about "technological realities"
  - Are these the results of real efforts that have failed or …???

How can policy provide continuous incentives for innovation?

- Policy instability is a disincentive to innovation
  - Subsidies (and related industries) are particularly prone to instability
    - "Rather have a lower rebate, say 15%, guaranteed for 5 years or more, than a large rebate, even more than 40%, that might last only a year or two" – SWH innovator
  - Standards less likely to go away (performance-based, RPS's)
- Price on a pollutant is one option
  - Differences between emissions trading and taxes, however

Anticipation of policy can induce investment and invention

- Entry, foment in patenting activity when expect new regulation or high pollutant allowance prices
  - In itself, increase in patenting theoretically increases available knowledge
- But when anticipate incorrectly, exit, stranded costs

Diffusion can work differently because of tech attributes…

- Diffusion of process vs. product, centralized vs. decentralized technologies
  - Involves issues of transparency, behavior, and public acceptance

Categorization of policy approaches can be a helpful, although incomplete, frame

Experience rates differ across technologies